PP-9702

Environmental Security Technology Certification Program

Cost and Performance Report

Powder Coating for Small-Arms Bullet Tip Identification

TACOM-ARDEC Picatinny Arsenal

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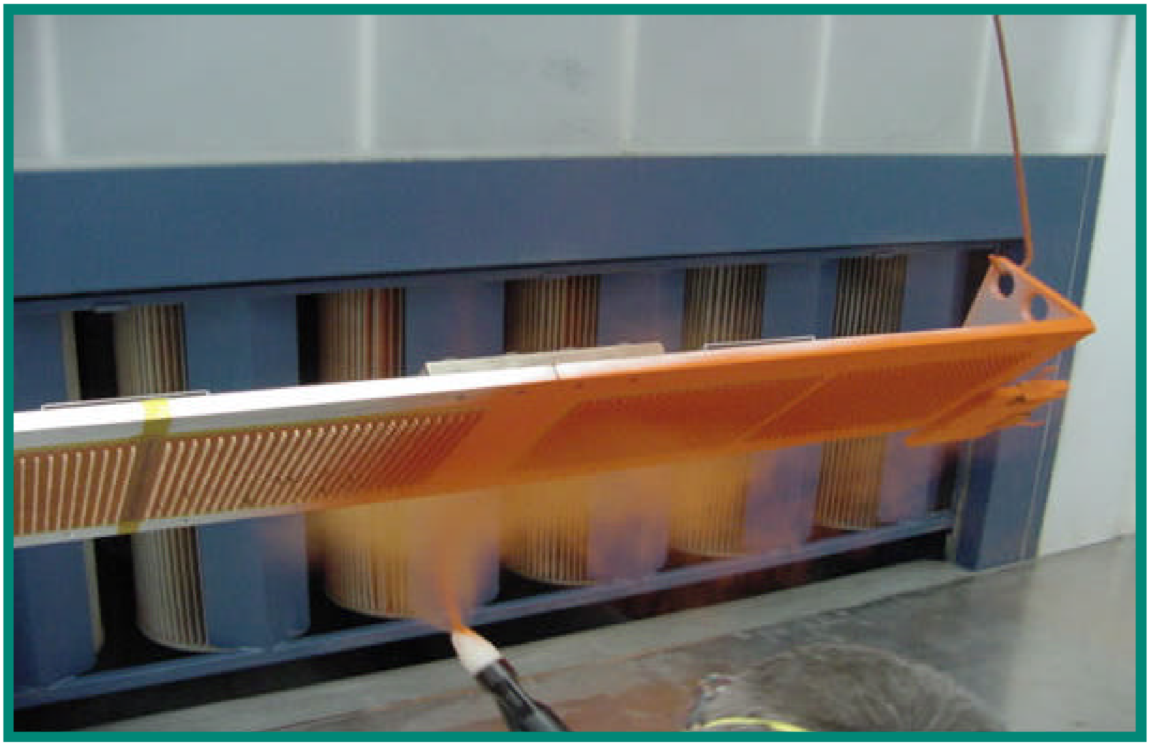

Powder Coating for Small-Arms Bullet Tip Identification

July 2003

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

COST & PERFORMANCE REPORT
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LIST OF ABBREVIATIONS AND ACRONYMS

AMC	Army Materiel Command
ATK	Alliant Techsystems
CFR	Code of Federal Regulations
CTC	Concurrent Technologies Corporation
ECAM	Environmental Cost Analysis Methodology
EHS	Environmental Health and Safety
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
GOCO	government-owned, contractor-operated
IRR	Internal Rate of Return
IWTP	Industrial Waste Treatment Plant
LAT	Lot Acceptance Testing
LCAAP	Lake City Army Ammunition Plant
M62	7.62 mm Tracer Bullet
NPV	Net Present Value
ODC	Ozone Depleting Compound
OEM	Original Equipment Manufacture
PPE	Personal Protective Equipment
ppm	parts per minute
PSI	Pounds per Square Inch
SARA	Superfund Amendments and Reauthorization Act
TACOM-ARDEC	Tank-Automative and Armaments Command — Armament, Research, Development, and Engineering Center
TRI	Toxic Release Inventory
VOC	Volatile Organic Compound

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1.0 EXECUTIVE SUMMARY

Powder coating technology is rapidly becoming a mainstream technology. Efforts to incorporate this technology into processes normally covered by spray or dip methods of application are continuous. An important aspect of a process change such as this is maintaining desired metrics and performance. This is especially true for military items such as ammunition.

Currently, all small caliber tracer and incendiary ammunition is produced at the Lake City Army Ammunition Plant (LCAAP) in Independence, Missouri, and is identified by applying a low volatile organic compound (VOC) paint to the projectile tip. This marking system is designed to aid soldiers and Marines using the ammunition in identifying the type of round they employ in a combat or training mission. Depending on caliber, the paint is applied either by dipping or by spraying the projectile tip in one of the final cartridge assembly steps. There are several inherent problems associated with this operation. First, the surface of the bullet must be free of contamination and particulates for the paint to have maximum adhesion and withstand subsequent handling operations. Currently, either methyl chloroform, an ozone depleting compound (ODC), or acetone, a VOC, is used to clean the bullet surface prior to painting. Second, the process is very inefficient. For example, the spray application process used in the high-speed manufacturing of 5.56-mm ammunition is only 5 to 10% efficient. The over-spray is captured in a filter hood, which is vented through the roof of the manufacturing building to the atmosphere, thus releasing the VOCs into the air. Paint passing through the filters and into the vent stack cures to the sides of the stack, eventually clogging the vent. The effluent VOCs are then vented into the manufacturing area rather than up the stack, creating a hazardous work environment. The alternative dip coating process used to coat the 7.62-mm and caliber .50 projectile tips is not environmentally controlled. The dip process uses ethyl acetate pre-cleaning, and, as in the spraying operation for the 5.56-mm cartridges, VOCs enter the work environments. The dip coating process is inefficient and costly, and it is difficult to maintain consistency in workmanship. Additionally, all the waste streams (unused paint and dry paint residue) must be treated as toxic waste.

This project, which focused on the orange tip identification process for the 7.62-mm trace cartridges, had performance objectives of meeting or exceeding current coating processes in terms of coating adhesion, quick and easy bullet identification, and eliminating hazardous waste associated with solvents. Concurrent Technologies Corporation (CTC) demonstrated that powder coating technology is a viable option for replacing the current dip method of paint application for bullet tip identification.

The demonstration showed that powder coating is feasible for this ammunition application. The standard lot acceptance test criteria for 7.62-mm tracer rounds were met or exceeded. VOCs were eliminated in the paint application process. The same or better visual identification was observed when compared to the current dip method. All wastes associated with the current technology would be eliminated by the implementation of this powder coating technology.

The cost of a powder coating system for the 7.62-mm tracer line of ammunition alone would render a payback of more than 7 years. Targeted payback of less than 3 years would prove not to be economically feasible, all other variables remaining equal. However, broadening the scope of powder coating to cover other calibers (5.56-mm, caliber .50, etc.) significantly improves the economic feasibility. The 7.62-mm tracer line was targeted for this demonstration and powder coating complimented the overall process with performance remaining constant throughout lot acceptance testing (LAT).

The main stakeholder for this technology is the ammunition manufacturing plant, LCAAP.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

The powder coating process was originally developed in the late 1960s in an attempt to obtain a more durable coating technology and as an alternative to liquid coatings. What differentiates powder coating from familiar traditional liquid coatings is the lack of a solvent base in the preparation and application of powder materials. With no solvent content, powder coatings do not emit toxic gases when applied or cured. Powder coatings are composed of finely ground plastic particles consisting of pigments, resins, binders, fillers, and hardeners. When exposed to heat, these plastic particles melt to form a continuous film of high durability and chemical resistance. Powder materials may be thermoplastic or thermoset. Thermoplastic powders do not chemically react in the cure phase. They are typically used for functional applications and applied in thick films (6-12 mils). The main advantage to thermoplastic is impact resistance and/or chemical resistance. Thermoset coatings are applied and then cured at a certain temperature for a period of time. The cure process causes cross-linking to take place, changing the powder into a continuous film that will not re-melt. Thermoset coatings are typically thinner (1-5 mils) and are usually applied to functional and decorative applications.

2.2 PROCESS DESCRIPTION

Most powder coatings are applied with electrostatic spray equipment. The general concept of powder coating using an electrostatic spray application system requires the following components: a pretreatment method to prepare the part surface for coating, an application system to apply the powder, a booth with recovery system to contain the process, a cure device to cross-link the material, and a conveyor system to move the part between these systems.

A charging system for electrostatic application has a voltage source that generates current through a voltage cable and carries it to the powder gun tip. The powder delivery system uses a pump to transport powder to the gun and out of the gun tip using compressed air. As the powder passes through the electrostatic field, it picks up a charge which is attracted to the grounded substrate. Following application, the part is conveyed to the proximity of a heat source for the curing of the powder. Under the heat exposure, the powder melts and becomes fully cured on the substrate.

Liquid paints (either high or low VOC) and powder paints share many similarities. The purpose of a coating is to form a plastic film over a substrate. To do so effectively, the coating must flow over the surface, cure in place, and attach itself to the surface with sufficient adhesion to be durable enough for the in-use criteria of the coated substrate. Generally, although there are exceptions, the best possible flow that results in a smooth consistent finish with the strongest adhesion is desirable.

Liquid and powders can also be similar in their chemistry of the paint type. Liquids are available in a wide variety of chemistries including thermosets, epoxies, urethanes, polyesters, and acrylics. These liquids are usually supplied as a two- or three-component system: a base resin (the actual plastic coating), a curing agent, and, occasionally, a cross-linking agent. These components must be mixed and applied before the curing agent decreases viscosity as cross-linking takes place. In general, the liquid paints incorporate some amount of carrier and/or solvent materials that must volatize and escape the polymer film while it is curing.

Powder materials are dry (resin only) and thus require no solvents or wet chemical carriers to be applied to the substrate. The thermoset powders are composed of two components, resin and curing agent, which are blended together and quickly frozen. The thermoset material is then ground into powder form. The powder materials also contain blocking agents which prevent chain-extensions from taking place until the materials reach an elevated temperature. The end result is that each particle of powder is, within itself, a complete paint system with pigments, resin, and curing agent in the appropriate proportions. This aspect of the technology allows similar paint chemistries in both powder coatings and traditional liquid paints. The powder particles are small enough to be fluidized and sprayed in a manner similar to liquids. However, for the powders to adhere to the substrate, the surface generally requires an electrostatic charge to be present on the powder particles, and the work-piece must be grounded.

The finished, cured films are somewhat similar and perform in similar manners whether applied by liquid or by powder. For example, epoxies applied by either method are chemically resistant and both are susceptible to ultraviolet radiation damage. The urethanes applied by either method have good abrasion resistance while the acrylics yield smooth surface finishes whether applied by liquid or by powder.

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

The applications of this technology in industrial coating are numerous — automotive, aircraft, marine, household appliance, sporting goods, computers, etc. The reasons for this growth are evident in that high quality finishes are obtained relatively easily while maintaining production line economy and environmental compliance. Virtually every industry that needs to apply a coating of either corrosion resistance, aesthetic value, or both has experimented with or now employs powder coating. Although powder coating has not been employed to identify small caliber ammunition, the extension of the technology to this area is not strained. The technological challenges in this program are similar with respect to every area powder painting that has been successfully employed. For specific examples of successful implementation of powder coating, sources such as the Powder Coating Institute should be consulted at www.powdercoating.org.

2.4 ADVANTAGES AND DISADVANTAGES OF POWDER COATING VS. LIQUID COATING TECHNOLOGY

Mixing. Since the components of the powder are already mixed and in powder form, no additional mixing is necessary. Liquids often require mixing in proper ratios and in some cases must be used immediately following this procedure. Mixing tools must be cleaned or discarded. Most excess liquid paint must be placed in storage, severely limiting its effectiveness or discarded as toxic waste.

Ease of Application. Generally, powders tend to be easier to apply and achieve more consistent coatings than liquids. When applied electrostatically, the powder coatings tend to be self-limiting and coat the work-piece with the same thickness in all areas. The electrostatic charge promotes a corona effect, which forces powder particles to wrap around the part and coat the edges slightly better than flat surfaces. If a mistake is made during curing, the powder can simply be blown off or wiped away and a new coating applied (assuming the cure process has not been applied). Also, with liquid coatings, edges are thin unless a concentrated effort is made to adequately cover these areas. Mistakes in liquid coating require stripping with solvents. The ambient environment is also less of a factor in the finish quality with powder coatings than with liquid coatings.

Clean up. Powder equipment such as guns and hoses are blown clean with compressed air. A color change can be accomplished in minutes. Liquid guns must be solvent-cleaned, even with water-borne paints, generating more hazardous waste than powder equipment.

Storage of Unused Material. Unused liquid paint cannot be stored in the gun or paint reservoir for more than a few hours. The material would cure in place and ruin the equipment. Excess thermoset liquids that have been mixed will eventually cure and have to be disposed of as a hazardous waste. Powders require elevated temperatures to flow and cure; therefore, they can be stored indefinitely in the spraying equipment without damage to either the material or equipment.

Storage of Bulk Materials. Most powders can be stored for years in normal manufacturing environments without damage. Most liquids have a limited shelf life and require flammable storage areas.

Curing Time. As compared with low-VOC liquid paints, the curing time for the powders is very low—10-20 minutes with a convection oven or 1-5 minutes with infrared, as opposed to hours or even days with some liquid paints. The disadvantage that powders have is that they must be heated to the 200°-400° F range to force the cure mechanism to start. Most low-VOC liquid paints cure at room temperature (65°-75° F) if given sufficient time or can be force cured at low temperature (120°-160° F) for a few hours. Curing time can vary widely for both powders and liquids, but in general, powders are cured much faster than liquids.

Film Properties. Because liquid paints must be formulated to allow the escape of carrier materials or solvents while the polymer film is curing, they are inherently not as dense as powders and therefore create a coating less durable or resistant to attack from the surrounding environment. Adhesion of powder coatings to most substrates is also better than liquid paints, adding to the durability of powder coatings. To date, however, exceptionally smooth lustrous finishes are difficult to obtain with powder coatings. Liquid paints continue to excel in this area, which is the main reason they are considered the only choice for automotive exterior finishes.

Booth Operation. Liquid paint booths must be completely ventilated of paint solvents and VOCs to the exterior environment. These fumes are released directly into the atmosphere or processed through a recovery system to diminish the emissions of toxic wastes. For large paint operations, this release can result in an enormous amount of waste and energy loss. Powder booths do not need to vent such volatiles; instead they use high efficiency filters to remove powder particles from the air, which are returned directly into the powder reservoir or disposed of as a nonhazardous waste. No air is discharged into the surrounding environment or into the atmosphere.

Considering the LCAAP application, the main limitation in the regulatory arena is the additional presence of the heat cure. This aspect of the technology creates a major safety concern due to the close proximity of energetic materials to the heat source. This was taken into consideration throughout the demonstration process, as the required temperature needed for curing is 300° F, whereas many powders typically require higher temperatures, and some even need a temperature of more than 600° F to cure properly. Nevertheless, this added safety issue requires material handling procedures for explosive materials to be highly scrutinized near where this application would occur.

3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The performance objectives for this project were to meet or exceed current coating processes in terms of coating adhesion, quick and easy bullet identification, and elimination of hazardous waste associated with solvents. Table 1 summarizes these performance objectives.

Table 1. Performance Objectives.

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)
Quantitative	Standard 7.62-mm Tracer Lot Acceptance Tests	Meet or Exceed Standard Lot Acceptance Test Criteria for 7.62-mm Tracer Rounds
	Eliminate Toxins in Paint Application Process	VOCs Eliminated in Paint Application Process
Qualitative	Visual Inspection of Coated Projectiles	Same or Better Visual Identification When Compared to Current Dip Identification Method

3.2 SELECTION OF TEST PLATFORM/FACILITY

The LCAAP in Independence, Missouri, is currently the only site that manufacturers small caliber ammunition (5.56-mm, 7.62-mm, and caliber .50) for military use.

3.3 TEST FACILITY HISTORY/LAYOUT

3.3.1 Lake City Army Ammunition Plant

Designated as a GOCO (government-owned, contractor-operated) facility, Remington Arms Corporation (later Remington-Dupont) was the first contractor to operate the plant from its inception in 1938 until 1988. Olin Corporation Winchester Division was the operating contractor from 1988 to 2000. Alliant Techsystems (ATK) became the operating contractor in April 2000 and is the current one. The plant was designated as the Lake City Army Ammunition Plant (LCAAP) in 1963.

The plant's basic structure and layout has not changed much since the 1940s. It is located on 3,935 acres and includes more than 450 buildings with more than 3.2 million square feet of floor space, a large ballistic testing range complex, a powerhouse, a fire station, and a wastewater treatment plant. Production of ammunition occurs in eight major manufacturing buildings. Currently, the plant is staffed with approximately 34 government employees, who provide quality assurance and administrative functions, and 1,200 ATK employees. The current production output of the plant is approximately 10 to 15% of the plant's original capability. Normal plant operation is currently 4 days a week on a 10-hour-a-day shift, 49 weeks per year, with a few processes operating two shifts per day.

The LCAAP produces small arms ammunition for military use only. This includes the 5.56-mm cartridge used primarily in the M16 rifle, the 7.62-mm cartridge used in armor and aircraft-mounted machine guns, the caliber .50 cartridge used in heavy machine guns, and the 20-mm cartridges used in Navy and Air Force main attack gun systems. The total annual production varies because of defense spending allowances, military logistics, the level of reserves available, and other factors. Twice in its history (1941-45 and 1968-70), the plant produced more than 10 billion cartridges per year. This required more than 4,000 employees per shift with the plant working 24 hours a day 7 days a week. Today, however, the plant is producing at its all time low (approximately 400-500 million cartridges per year), which accounts for the low plant utilization and the current 1,200 employees.

The principal industry in ammunition production is metal-forming. Raw materials in the form of brass cups enter the plant and undergo several forming operations using precision presses to form the material into cartridge cases and bullets. In some cases, bullets are produced by outside sources. Each production step is carefully monitored to ensure product consistency. Much of the manufacturing equipment used in these operations dates from the plant's opening. For the 5.56-mm operations (by far the largest proportion of the plant's total production since the 1970s), a modern, state-of-the-art high-speed process was implemented, which gives the plant an output of more than 1,200 parts per minute (ppm) as compared to 60 ppm on the conventional equipment used to manufacture the 7.62-mm and caliber .50 items. Following cartridge production, there are operations for loading, packing, inspection (both interim and final), testing, quality control, and transportation.

3.3.2 Concurrent Technologies Corporation (CTC)

The demonstration at CTC, Johnstown, Pennsylvania, was performed at CTC's Manufacturing Technology facility, a state-of-the-art facility using the powder coating booth and oven. This operation can switch between various techniques and can evaluate different coating characteristics. Many different configurations of parts have been coated at this facility.

3.4 PHYSICAL SET-UP AND OPERATION

The system demonstrated at CTC consisted of a conveyor that carried projectiles through various stages in the painting process. Two test jigs, each holding approximately 2,200 projectiles, were suspended from the conveyor. A jig at the start of the process is shown in Figure 1.

The particular jig shown had two masking types applied to it, as evidenced by the different colors (clear on the left side, amber on the right side). The masking was important to ensure that the paint adhered to the desired surfaces and that significant paint buildup on the jig surface did not occur. Because the apparatus was grounded, when an electrostatic charge was applied, the paint was attracted to the projectiles, which acted as mini lightning rods. After the projectiles were loaded in the jig (by hand during CTC's demonstration), the conveyor brought the jig into the painting booth where the paint was sprayed on, as shown in Figure 2. The gun used was a Nordsen Electrostatic Versa-Spray Corona manual powder spray gun, and the paint an epoxy-based thermoset.

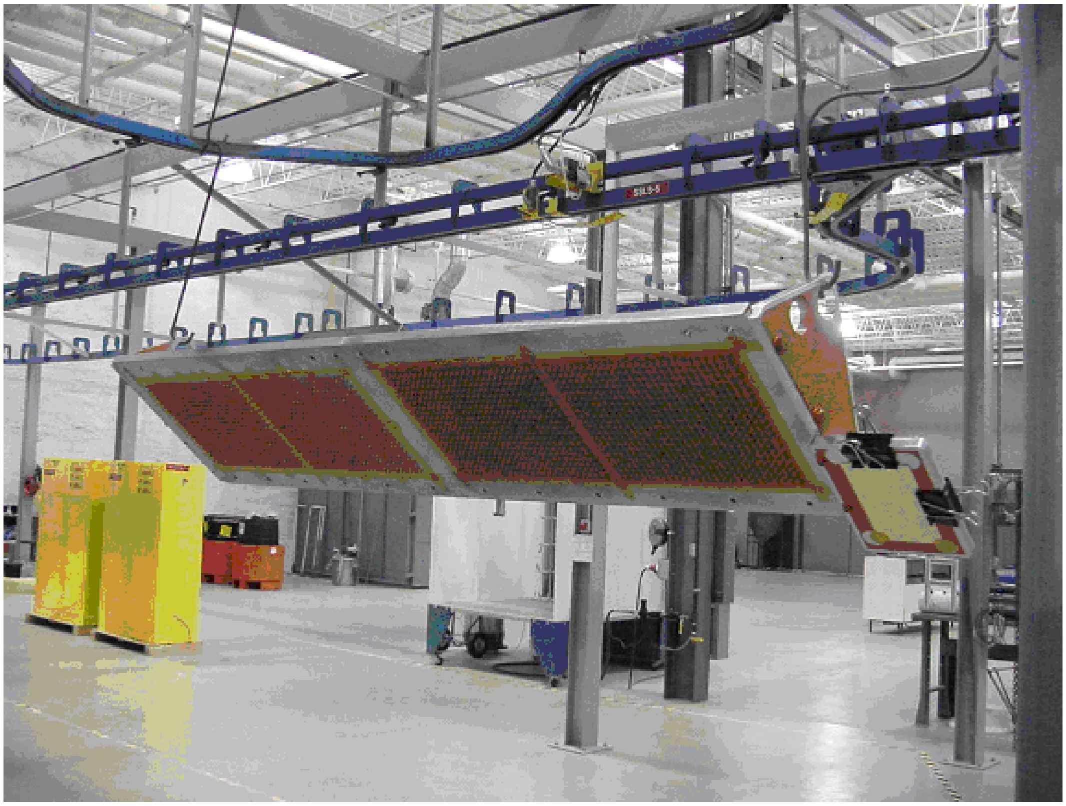

Figure 1. Concurrent Technologies Corporation Test Jig.

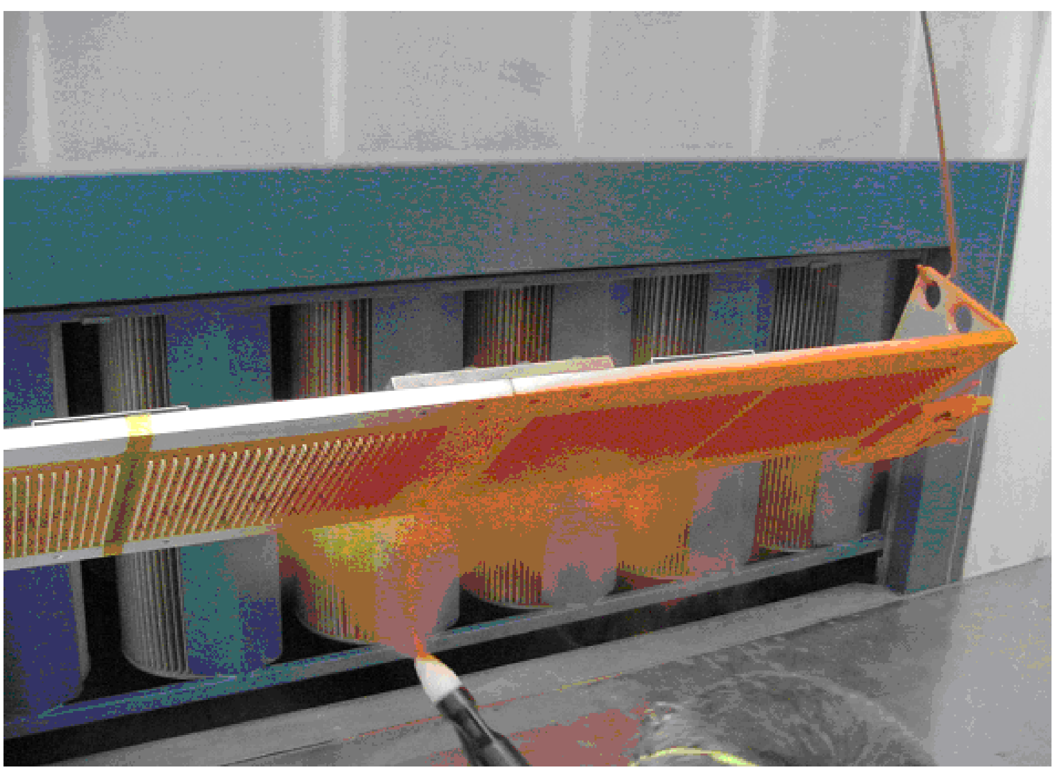

Figure 2. Paint Spray Booth.

Figure 3 shows the assembly being heated in an oven at approximately 300° F for 46 minutes.

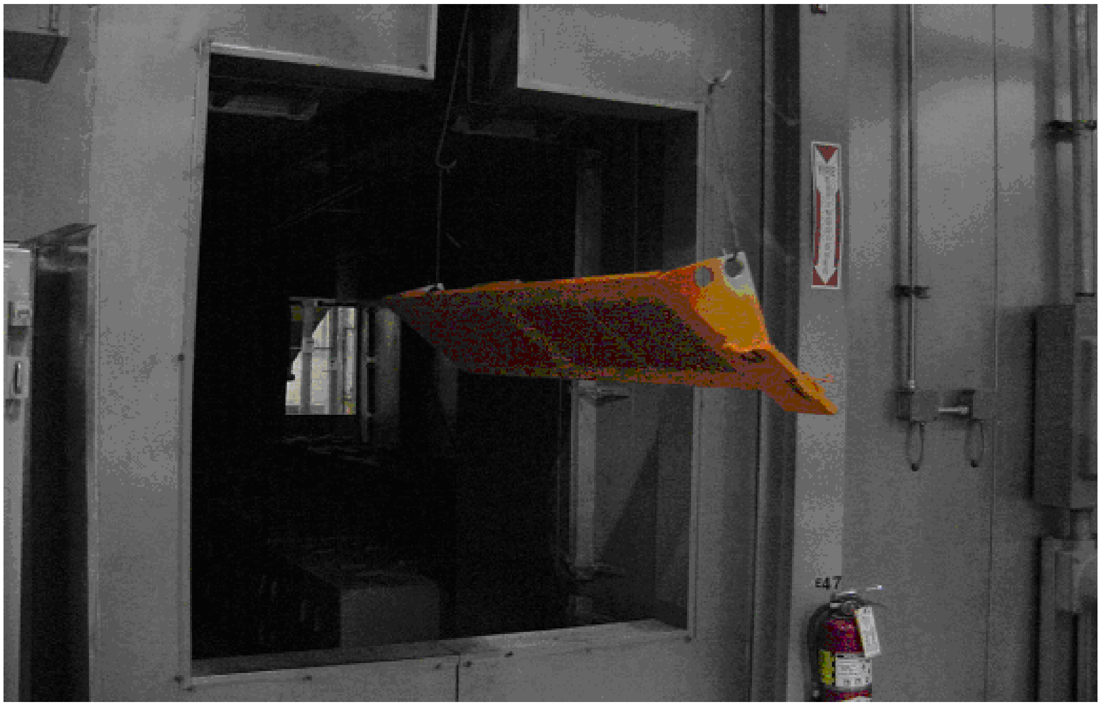

Figure 3. Curing Oven.

The projectiles snaked through the oven on the conveyor, exited the oven, and were cooled down. The cool-down period was more critical for the jig (larger mass) because the heat had to dissipate before another run could begin. In all runs, the projectiles were not pretreated or prepared in any way. This was not required and helped to demonstrate the superior adhesive properties of this powder coating process.

3.5 SAMPLING AND MONITORING PROCEDURES

For the demonstration, a total of 50,000 7.62-mm tracer projectiles were produced on the same machine and exposed to conditions that did not vary. Of these 50,000 7.62-mm tracer projectiles, approximately 20,000 were held back at LCAAP as controls, while the remaining 30,000 were sent to CTC for demonstration. After the projectiles were exposed to the powder coating, they were shipped back to LCAAP. The powder-coated projectiles along with the controls were then loaded into complete cartridges on the Manurin® loaders. After loading, both the powder-coated and control samples underwent LAT and side-by-side tracer testing. This consisted of actual firing at the LCAAP firing range and documenting whether the tracer could be seen with the naked eye at several points down range.

3.6 ANALYTICAL PROCEDURES

Analyzing the test data was routine procedure, and the pass/fail criteria for ballistic LAT is well-documented and straightforward. The complete testing performed at LCAAP may be found in Appendix A of the final report (reference 1).

4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE DATA

All performance data may be found in Appendix A of the final report (reference 1). Table 2 summarizes the test results for the powder-coated samples and Table 3 summarizes the test results for the control samples.

Table 2. Test Results for Powder-Coated Projectiles.

Test		Result	Acceptance
7.62-mm Function and Casualty Acceptance Test	Ambient (70° F)	All 200 rounds functioned without incident.	Passed
	Hot (125° F)	All 200 rounds functioned without incident. There was one observed large primer leaker at this temperature.	Passed
	Cold (-65° F)	All 200 rounds functioned without incident.	Passed
M62 Accuracy	Ambient	Average mean radius of 5.15 inches at 600 yards. Sample met requirement.	Passed
M62 Bullet Integrity	Ambient	Sample met requirement as all 200 rounds tested showed no signs of fragmentation.	Passed
M62 Trace Test	Ambient Outdoor Range	Of the 200 rounds tested (100 in M60 gun and 100 in T65 gun), there were four visual defects observed not exhibiting the desired trace performance at either 15 yards, 100 yards or 850 yards downrange (all M60 gun).	Passed
Velocity	78 ft from muzzle	2670 ft/s with 11 ft/s standard deviation	Passed
Chamber Pressure	PSI	All were within average and maximum acceptable values	Passed
Port Pressure	PSI	Within average acceptable values	Passed
Action Time		Within acceptable value	Passed
Waterproof	Testing for observable leakages	First sample of 50 rounds had eight failures (accept on three failures, retest on 4-9 failures). Second sample retest had 13 failures (pass on nine cumulative failures, reject on 10 cumulative failures). 21 total failures out of 100 rounds tested.	Failed
Case-Residual Stress	Mercurous Nitrate	All rounds exhibited no case splits after treatment.	Passed
Bullet Extraction	60-lb threshold	All rounds tested met requirement.	Passed
Gauge and Weigh	Cartridge dimensions	One major defect out of 200 (overall length) for the first sample and one out of 200 (length to shoulder) for retest.	Passed

Quality spot checks were also conducted for visual identification of the coated projectiles. To get a better feel for what the level of acceptance was, 100-bullet samples of both powder-coated bullets and controls were taken, which were categorized into four different sections: good bullets, bullets that had some inconsistencies (scratches), bullets that had ~ 25% loss, and bullets that had 50% loss or greater. The ratios for each were very similar, which suggested that the same criteria had been applied to each sample. A comparison of these coatings side-by-side is shown in Figure 4. The powder-coated bullets are pictured below the control bullets.

Table 3. Test Results for Control Sample.

Test		Result	Acceptance
7.62-mm Function and Casualty Acceptance Test	Ambient (70° F)	All 200 rounds functioned without incident.	Passed
	Hot (125° F)	All 200 rounds functioned without incident.	Passed
	Cold (-65° F)	All 200 rounds functioned without incident.	Passed
M62 Accuracy	Ambient	Average mean radius of 5.71 inches at 600 yards. Sample met requirement.	Passed
M62 Bullet Integrity	Ambient	Sample met requirement as all 200 rounds tested showed no signs of fragmentation.	Passed
M62 Trace Test	Ambient	All 200 rounds tested (100 in M60 gun and 100 in T65 gun) were observed exhibiting the desired trace performance at 15 yards, 100 yards, and 850 yards downrange.	Passed
Velocity	78 ft from muzzle	2680 ft/s with 12 ft/s standard deviation.	Passed
Chamber Pressure	PSI	All were within average and maximum acceptable values.	Passed
Port Pressure	PSI	Within average acceptable values	Passed
Action Time		Within acceptable value	Passed
Waterproof	Testing for observable leakages	First sample of 50 rounds tested had three failures. No need to retest as three failures was within the acceptable limits. The number of maximum cumulative failures for 50 rounds tested is three.	Passed
Case-Residual Stress	Mercurous Nitrate	All rounds exhibited no case splits after treatment.	Passed
Bullet Extraction	60 lb threshold	All rounds tested met requirement.	Passed
Gauge and Weigh	Cartridge dimensions	All rounds met requirement. No major defects; no retest required.	Passed

Figure 4. Comparison of Finished Projectiles.

The paint integrity of both samples was compared. Basically, the powder coating was very resilient and a strong improvement to the current process. No flaking off was evidenced in any stage of the process. The water-based dip process, on the other hand, flakes off consistently and does not adhere very well to the bullet tip, and orange paint is especially difficult to apply.

4.2 PERFORMANCE CRITERIA

Table 4. Performance Criteria.

Type of Performance Objective	Primary Performance Criteria	Actual Performance Objective Met?
Quantitative	Standard 7.62-mm Tracer Lot Acceptance Tests	Yes
	Eliminate Toxins in Paint Application Process	Yes
Qualitative	Visual Inspection of Coated Projectiles	Yes

4.3 DATA EVALUATION

All testing was performed in accordance with the standard testing conducted on every lot of similar ammunition produced at LCAAP. Comparison of the two samples from the demonstration offered a baseline for performance that is reliable and competent. There were some deviations evidenced between the samples. Tests concerned with trace performance, gauge and weight, residual stress, and primer leakage were independent of the method of coating the projectiles. These tests were incendiary tracer mixture, cartridge case dimensions, cartridge case dynamics, and the primer mixture inserted into the cartridge, respectively. These tests are conducted routinely and vary quite frequently from sample to sample within acceptable limits.

On the other hand, the accuracy and velocity tests, which determine product reliability, were deemed most likely to exhibit variation. However, they were indistinguishable; either result could have passed for either sample. The results of these tests strongly support the contention that powder coating technology is a viable method of tip identification for small caliber ammunition.

One test failure was the waterproof test on the powder-coated sample. The waterproof test tests for leaks in the cartridge through the bullet/cartridge interface. A sample of 50 was taken, and if there were four or more "leakers," the lot would be retested with a double sample size. The control sample had three leaks out of 50. However, the powder-coated sample had eight leaks out of 50. During the double sample, 13 out of 100 leaked for the powder-coated sample. With this result, the lot would have failed and would have been rejected. However, the result can be easily explained by the additional material handling received by the powder-coated samples.

M62 tracer cartridges, which use the 7.62-mm projectile, do not have a boat tail on the end of the projectile because the incendiary mixture is inserted before the core. Typically, this boat tail allows a smoother and tighter fit around the cartridge when the projectile is inserted. These rounds are lubed with mineral oil before loading to help make the procedure more uniform and to ease the process.

Mineral oil was applied to the control samples and the powder-coated samples before any coating was applied. The control sample did not have any other application to the projectiles before loading. The powder-coated projectiles, on the other hand, were shipped to CTC's facility in Johnstown, Pennsylvania. These projectiles were then hand loaded into test jigs for coating, exposed to a temperature of 300° F in the curing oven for 46 minutes, cooled down, hand-packed in containers, and shipped back to LCAAP where they were unpacked and placed in a container prior to loading.

The additional material handling of the powder-coated projectiles throughout the process nullified the effect of the mineral oil application. The mineral oil was not reapplied to the powder-coated sample. This oversight will be addressed in the future by applying mineral oil directly before loading occurs and underscores the importance of the mineral oil application for the M62 rounds.

The data obtained from testing demonstrates the viability of powder coating in this environment. The fact that there were no noticeable differences in results from the control sample and the powder-coated sample (aside from the leak test, which could be explained), demonstrates the effectiveness and feasibility of this technology.

4.4 TECHNOLOGY COMPARISON

The traditional dipping and powder coating methods were the two comparisons made during this project. Due to the unique characteristics of the required painting application for small caliber ammunition tip identification, apparently powder coating is the only current alternative method of applying paint to the end of the projectiles that would both coat the required area evenly and allow for the elimination of VOCs. This was a consideration in selecting the powder coating method of paint application.

5.0 COST ASSESSMENT

5.1 COST REPORTING

The primary objective of the cost assessment is to determine whether a powder coating process could be implemented with an acceptable payback period. A standard questionnaire was used to obtain information regarding the costs associated with the current 7.62-mm painting line at LCAAP. The 7.62-mm questionnaire was completed by CTC during a site visit to LCAAP, and the information was entered into the Environmental Protection Agency's (EPA) pollution prevention cost accounting software, P2 Finance (reference 2) according to the Environmental Cost Analysis Methodology (ECAM). The software performs the calculations for payback period, net present value (NPV), and internal rate of return (IRR).

5.2 COST ANALYSIS

It should be noted that ATK will need to perform facility modifications to incorporate the powder coating system into the current material handling (conveyor) system at LCAAP. The figures shown in Table 6 are the maximum allowable expenditures required to stay within the specified payback period. The dollar amounts in Table 6 represent the total cost, including equipment and facility modifications. The cost of facility modifications are estimated at $40,000.

The following assumptions were made to complete the cost analysis shown in Table 5.

- The powder coating system would require one operator.
- EHS costs (permitting and reporting) for powder coating would be the same as the current process; therefore, EHS issues were not factored into the cost analysis.
- The powder coating system will include a reclamation system so the unused powder would be reclaimed and reused.
- Powder coating could increase the parts per minute (ppm) and therefore reduce the overall annual labor cost by reducing the number of days needed to produce the 6 million tracer rounds.
- The cost of the orange paint used in the current process for tip identification is $21.72.

This long payback period can be attributed to the relatively low production rate for the 7.62-mm projectiles, and the infrequent basis on which these projectiles are manufactured. Although the current process is not efficient, the low production rate results in a low annual cost for painting the projectiles using the current process. As a result, the timeframe required to pay back the cost of an initial powder coating investment is longer.

Implementation for the 7.62-mm cartridge line alone is not economically justifiable due to the current low throughput rate, the facility modifications required for material handling, and the uncertainty in regard to the health and safety risks associated with installing a powder coating process in an ammunition manufacturing facility. The payback period would be much greater than 7 years, whereas 1 to 3 years is desirable. However, powder coating is a versatile technology that is applicable to several other calibers of ammunition at LCAAP, and its implementation for a wide range of ammunition may be appropriate. The cost analysis from a previous study for the 5.56-mm round (reference 3) showed that powder coating was more economically justifiable for this caliber ammunition. Also, as powder coating is more widely implemented, the elimination of hazardous solvent usage would increase and the occupational health of workers would improve.

For full details, see the complete cost analysis performed by CTC (reference 4).

Table 5. Input Parameters for 7.62-mm Cost Analysis.

Category	Input Parameter	Current Tip ID Process at 133 ppm	Powder Coating Process at 200 ppm	Powder Coating Process at 400 ppm
Capital Costs (One-time fees)	Equipment and Installation Cost	$0	$0	$0
	Facility Modification Cost	$0	$0	$0
	Total Capital Investment	$0	$0	$0
Labor	Number of Operators	One per shift	One per shift	One per shift
	Pay Rate	$21.85	$21.85	$21.85
	Shift Length (hours)	10 per shift	10 per shift	10 per shift
	Number of Shifts	One per day	One per day	One per day
	Production time per shift (hours)	10 hours	9 hours	9 hours
	Operating Days per Year[1]	75 days	56 days	28 days
	Downtime (for maintenance)[2]	0 hours per year	55 hours (1 hour per day)	28 hours (1 hour per day)
	Total Annual Labor Cost	**$16,388**	**$12,236**	**$6,118**
EHS	Reporting, Training, PPE, etc.	Will not change	Will not change	Will not change
Materials	Paint or Powder Usage per Year[3]	160 gallons	62 pounds	62 pounds
	Paint or Powder Cost[4]	$21.72 per gallon	$19.85 per pound	$19.85 per pound
	Paint or Powder Annual Cost	$3,475	$1,230	$1,230
	Solvent Usage per Year (Ethyl Acetate)[3]	5,000 pounds	N/A	N/A
	Solvent Cost[5]	$0.75/lb	$0	$0
	Solvent Annual Cost	$3,750	$0	$0
	Total Annual Material Cost	**$7,225**	**$1,230**	**$1,230**
Waste	Category of Waste	Some hazardous and some nonhazardous	Nonhazardous	Nonhazardous
	Transportation Fees	None	None	None
	Disposal Method	Nonhazardous to industrial waste	Industrial waste	Industrial waste
	Total Amount of Waste Generated	One drum of solvent waste	100 pounds per year	100 pounds per year
	Disposal Rate[6]	$100 per drum	$3.00 per pound	$3.00 per pound
	Total Waste Disposal Fees	**$100**	**$300**	**$300**

Notes:
1. ATK stated that they currently produce approximately 6 million 7.62-mm tracer rounds per year.
2. The hours for maintenance are accounted for because the current throughput rate produces only 80,000 rounds per day (stated by ATK). Therefore no additional hours are added into the cost for maintenance for the current process. Similarly, for the powder coating system alternatives, it was assumed that 1 hour out of a 10-hour shift will be for start-up, shutdown, and maintenance combined. It was assumed that the powder coating system would be producing the indicated ppm for 9 hours out of a 10-hour shift.
3. Data provided by ATK.
4. The calculation for the amount of powder needed to coat 6 million bullets was determined assuming an overall transfer efficiency of 90.25%. The coverage rate supplied by the Sherwin-Williams was 128 ft 2/mil and the thickness assumed for the bullet tips was 1 mil.
5. Cost is based on an informal quotation of $0.75/lb for a quantity of 10,000 lb from a representative at Mid-State Chemical Company.
6. ATK stated that they produce approximately two drums of hazardous waste per year, combining the operations for both 5.56-mm and 7.62-mm painting lines. CTC assumed that one half of the total waste was from the 7.62-mm solvent cleaning process.

5.3 COST COMPARISON

Table 6 and Table 7 illustrate the differences in scope of implementing powder coating technology across different calibers. Table 7 illustrates the effect of including other calibers (5.56-mm) into the scope of implementing this powder coating technology. This analysis was done prior to the projects focus exclusively on the 7.62-mm tracer rounds. Other rounds including caliber .50 would also add another dimension to the cost-benefit analysis.

The ultimate cost of implementing a powder coating process that meets the need for production capacity has several variables that significantly impact any estimate. A major factor in the cost of implementation will be the volume of production, which directly affects such end items as oven size and the size and type of material handling system used. These factors account for a large percentage of the final cost.

Table 6. Allowable Capital Expenditure at Various Payback Periods for Two Different Powder Coating Systems for 7.62-mm Tracer Rounds.

Payback Period	Total Capital Expenditure (includes equipment and installation costs)	
	200 ppm System	**400 ppm System**
2 years	$18,750	$29,750
5 years	$44,400	$70,000
7 years	$58,250	$93,750

Table 7. Allowable Capital Expenditure for 5.56-mm Cartridge Painting at Various Payback Periods.

Payback Period	Total Capital Expenditure (includes equipment and installation costs)
1.75 years	$200,000
2.5 years	$297,000
3 years	$360,000

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6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

The scope of caliber coverage will determine how cost beneficial the implementation of a powder coating system will be at LCAAP. Just by adding in the 5.56-mm line of ammunition into the mix, the payback periods listed in Table 7 allow for more than a 10-fold increase in allowable capital expenditures. The amount of ammunition to be coated is the main driver. The fixed cost portion would remain relatively constant as the scope increases with minor flow-rate considerations in oven size. Variable costs should be a consistent percentage that is relatively independent of operational size.

However, the cost analysis was performed on only one type of 7.62-mm ammunition. If expanded to all 7.62-mm ammunition, powder coating could provide a faster payback period based on an increased volume of production. For powder coating to provide a positive, long-term cost impact, CTC recommended that it be used on all types of 7.62-mm ammunition.

One factor that is not easily quantified is the current dip process at LCAAP, which uses a hazardous chemical (ethyl acetate). By implementing powder coating, ATK can eventually eliminate the use of this material in all wet spray and dip coating processes used for tip identification at LCAAP.

6.2 PERFORMANCE OBSERVATIONS

This powder coating project successfully demonstrated that the process of applying paint to the tips of ammunition for identification purpose could be modified from the current spray and dip methods. Besides the elimination of VOCs in the process, the quality and adhesion demonstrated by powder coating was clearly superior. The main consideration is whether or not the ballistic performance is altered in such a way as to lower the performance below acceptance criteria. This was not seen during the demonstration. The results obtained through this project prove that powder coating technology is a viable alternative to the traditional dip method of bullet tip identification.

The adherence of the paint to the tip for the powder-coated sample greatly exceeded the current method. Since the powder-coated sample had such a high bonding strength to the tip of the bullet, it was basically a permanent change. The application of this technology significantly raised the bar in terms of coating strength.

6.3 SCALE-UP

The general consensus is that 5.56-mm ammunition would have to be included in any proposal for implementing powder coating at LCAAP. The capital for equipment purchase for a larger system would be much more in line with a state-of-the-art system that would be interchangeable between different calibers and bullet types. All of the 5.56-mm ammunition is coated, as opposed to only the tracers in the 7.62-mm line. The M855 ball round is painted green and the M856 is painted orange. The volume of production of 5.56-mm ammunition is the highest at LCAAP and would obviously offer cost incentives. At a large throughput, commercial powder technology vendors would be more willing to address the safety issues of installing the technology in an ammunition factory.

6.4 OTHER SIGNIFICANT OBSERVATIONS

Powder coating technology is still an evolving technology. The current oven cure method at 300° F requires a cure time of approximately 7 to 10 minutes for the 7.62-mm bullets. Reportedly, there is a new technology that would use a "flash cure." This utilizes a portion of the infrared range in the electromagnetic spectrum to cure a part in approximately 5 seconds. This claim would have to be backed up and tested but could prove to be very beneficial to the amount of oven or cure space needed, especially with the high volume 5.56-mm line of ammunition. Another concern currently is that there is only one supplier.

6.5 LESSONS LEARNED

One lesson learned concerns the treatment of sample projectiles prior to testing. At the time, it was not realized how important the application of mineral oil was to the process. The effect of transporting the powder-coated projectiles and the extra material handling they were exposed to in essence nullified the intended effect of the mineral oil. This was evidenced by the seal between the projectile and case not being effective, and failure of the casemouth waterproof test for the powder-coated sample was the result. This was a very minor failure that was easily explained, but coating both samples just prior to loading would have alleviated this issue.

The lesson here for future projects is to treat both control and experimental samples as close to the real environment as possible, even when it appears inconsequential. In retrospect, the mineral oil should have been applied after the powder-coated projectiles were received at LCAAP. This would have made the results of the waterproof test more accurate.

6.6 END-USER/ORIGINAL EQUIPMENT MANUFACTURE (OEM) ISSUES

The main stakeholder for this technology is the ammunition manufacturing plant, LCAAP. The important issues for this facility include the following.

- Decreased environmental exposure to the Army Toxic Release Inventory (TRI).
- Ease of implementation and operation of the proposed technology.
- Equal or better paint finish quality.
- No effect on ballistic performance, production performance, or quality control systems.
- Maintaining safety standards with a heat source that may be near explosive processes.

For the depot representative and the end user, i.e. the soldier or Marine, the implementation of the proposed system must be transparent to the entire system, specifically:

- The identification color scheme must be equivalent to the current scheme.
- No impact to the weapon functioning.
- Paint adhesion equal to or better than the current technology.

6.7 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

Regulatory issues were not the mandated driver for this program, although decreasing waste associated with the current process is highly desirable. This project focused on removing the VOCs used in the current process while increasing process efficiency and paint adhesion.

Two regulatory directives govern the reduction of LCAAP pollution. On the federal level, guidance in this area is primarily determined by the TRI, which uses the following as reference:

- Army Materiel Command (AMC) Pollution Prevention Plan
- EPA 40 Code of Federal Regulations (CFR)
- The Pollution Prevention Act of 1990
- Superfund Amendments and Reauthorization Act (SARA) Title III Form R
- Clean Air Act of 1990
- Executive Order 12856

On the state level, guidance is provided by the Missouri EPA regulations under 10 CFR and EPA Facility Pollution Prevention Guide, Document No. EPA/600-92/088.

The LCAAP has met the federal and state guidelines for pollution prevention each year since they were enacted. However, the continual reduction of the TRI at LCAAP is a goal worthy of pursuit since each successive year finds stricter goals for the expected waste stream dictated by evolving federal and state regulations.

In the cartridge tip identification process, the main pollutants are VOCs discharged into the atmosphere as a result of paint solvent flash-off and drying, and paint sludge, which is produced due to the inefficiency of the process. This waste is processed in one of two ways. Paint residue conveyed through the waste water system, is processed through the plant's industrial waste treatment plant (IWTP). Filters and rags containing paint residue are disposed of by removing them from the plant to a toxic waste landfill. Appropriate environmental statutes regulate each of these systems.

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7.0 REFERENCES

1. ESTCP Final Report "Powder Coating for Small-Arms Bullet Tip Identification" TACOM-ARDEC, Picatinny Arsenal, July 26, 2002.

2. Environmental Cost Analysis Methodology (ECAM) Handbook, National Defense Center for Environmental Excellence, Johnstown, Pennsylvania, for the Environmental Security Technology Certification Program (ESTCP). Contract No. DAA21-93-C-0046, Task No. N.098, March 29, 1999.

3. "Interim and Cost Analysis Report" dated, December 29, 2000, and submitted by Concurrent Technologies Corporation, Johnstown, Pennsylvania, under GSA Contract No. GS-23F-0061L, US ARMY TACOM Order No. DAAA 21-93-C-0046, Task No. N.212, CDRL No. A005.

4. Cost Analysis Task 3 Report dated September 6, 2001, and submitted by Concurrent Technologies Corporation, Johnstown, Pennsylvania, under GSA Contract No. GS-23F-0061L, US Army TACOM-ARDEC No. DAAE30-01-R-0412.

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APPENDIX A

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